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# DESCRIBING THE EFFECT OF GRAZING ON NITROGEN LEACHING IN WINTER FORAGE-RYEGRASS ROTATIONS

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## Abstract

Animal feeding over the winter is a critical phase in pasture-based dairy farms with important influence on animal performance. An increasingly common management practice in New Zealand is wintering pregnant non-lactating cows on forage crops, thus avoiding damage to the pasture during wet periods. Due to the large amount of standing dry matter of forages, cows are typically grazed on blocks or strips where stocking densities can be as high as 300-600 cows/ha. Grazing at such high stocking densities results in the return of large amounts of excreted nitrogen (N) to the paddock during winter when risk of losses are high. Treading damage and soil compaction are also likely to occur because grazing is often done in wet conditions. This can exacerbate denitrification losses and potentially reduce growth of pasture established after the forage crop. While the area used for winter grazing is relatively small, these winter forage grazing paddocks are believed to contribute a disproportionately large part of annual farm nutrient losses as a result of intensive stock grazing on soils with high moisture content.

Wintering systems can vary in the type of the forage crop used, the grazing management, fallow period, as well as the land use after grazing. Assessing the impact and identifying good management for wintering systems for different climates and soils is a challenging task. Computer simulation models are crucial tools for this, complementing field research. In this study, the Agricultural Production Systems Simulator (APSIM) was setup to describe winter forages growth and grazing followed by the establishment of ryegrass pasture. Firstly, data from trials in the Canterbury region were used to guide model refinement and assess its performance for wintering systems. Changes made to APSIM included some forage crop parameters and the dynamic change of soil physical properties, such as macroporosity, bulk density and hydraulic conductivity, in response to animal trampling. This setup was then used to analyse the effect of the duration of the fallow period after winter forage grazing on N leaching.

## Introduction

Pasture-based dairy farms, typical of New Zealand and Australia, employ an intensively managed rotational grazing system throughout the year. Feeding the pregnant non-lactating animals over winter is increasingly recognised as a critical phase of pastoral farming that has an important influence on animal performance (e.g. Troccon 1993; Judson et al. 2010). A common management practice is wintering the cows on high yield forage crops over a 10-week period during winter to cost effectively provide the required amount of winter feed (Smith et al. 2012). Under this management practice, where cows are grazed on blocks or strips, stocking densities can be as high as 300-600 cows/ha (Drewry et al. 2008). This often occurs in wet conditions, likely causing treading damage and compaction, thereby exacerbating N losses and potentially reducing upcoming pasture growth (Singleton & Addison 1999; Thomas et al. 2008). Furthermore, grazing winter forage crops at high stocking densities results in the return of large amounts of excreted nitrogen (N) to the paddock during a period when risk of leaching is high. While the area used for winter grazing is relatively small, typically less than 15% of the farm, these winter forage grazing paddocks are believed to contribute a disproportionately large part of annual farm nutrient losses as a result of intensive stock grazing on soils with high moisture content (Chrystal et al. 2012; Shepherd et al. 2012; Smith et al. 2012).

Computer models are increasingly being used to simulate farming systems. Results for simulations are used to complement experimental studies and help to understand the implication of various management options in different environmental conditions. Such tools can aid on farm management and inform policy making and compliance. Identifying good management practices for wintering systems with different climates and soils is a challenging task, as such systems can vary in the type of forage crop used, the grazing management, fallow period, as well as the land use after grazing. Process-oriented modelling approaches are better suited to deal with such variety as they depend less on local calibration. The APSIM model framework has been widely used in New Zealand to simulate pasture systems and crop rotations, however evaluation is lacking for winter forage crop grazing and rotation with pasture.

The objective of this study was to assess and refine the performance of APSIM to simulate N leaching in wintering systems. The major processes considered were plant growth, the water and N balances, and the effect of soil compaction. Preliminary results using experimental data from a rotation of forage rape and ryegrass, established at Lincoln, are presented here.

## Material and methods

### *Experimental setup*

The study was conducted during 2012 in Lincoln in the Canterbury region of New Zealand. The soil was a poorly drained Flaxton Deep Silty Loam and the rotation consisted of forage rape (*Brassica napus ssp. biennis*) and ryegrass (*Lolium perenne*). The rape was sown on the 14-Mar-2012, either by direct drilling or after intensive tillage (mouldboard plough and power harrow). Nitrogen fertiliser was applied at a rate of 50 kg N/ha on the 20-Mar-2012 (Cropzeal 20) and 30- Apr-2012 (urea), and irrigation was applied twice in May (46 and 33 mm) over rape and then in November on ryegrass (38 and 17mm). On the 2-Jul-2012 grazing was simulated by removing the rape biomass from the field after cutting it at approximately 20 cm above ground level. Within the tillage treatments, split plots were then established with factorial combinations of +/- treading and +/- urine. Plots were then compacted using an artificial cow hoof machine with a downward pressure of 225 kPa per hoof to simulate treading, followed by urine application at a rate of 600 kg N/ha. Each treatment was set up in four replicates. After a fallow period of about 10 weeks, ryegrass was sown on the 25-Sep-2012, by either direct drill or intensive tillage according to the method used to establish rape. The grass was then cut to a residual DM of about 1500 kg DM/ha on the 11-Dec-2012 and to ground level on 23-Jan-2013. Measurements relevant for the study described here are the yield of rape and ryegrass, soil moisture, and soil nitrate ($NO_3$) and ammonium ($NH_4$) concentrations. Soil moisture at 0-15 cm depth was measured by Water Content Reflectometers (Campbell Scientific CS616) every 15 minutes, daily averages are used here. Soil moisture was also determined fortnightly at deeper layers using a Neutron Probe (CPN503TDR hydroprobes) in a quarter of the plots. Soil samples were collected at least fortnightly at depths of 0-7.5 cm and 7.5-15 cm for analyses of soil mineral N concentration. Soil bulk density was also determined fortnightly.

***Modelling simulation setup***

All simulations were conducted using the Agricultural Production Systems Simulator (APSIM) modelling framework, Version 7.7 r3807 (Holzworth et al. 2014, see also www.apsim.info). The primary modules used in the simulation for this study included the soil module SWIM2 (Verburg et al. 1996), the SurfaceOM and SoilN modules (Probert et al. 1998) for soil carbon (C) and N transformations, the pasture module was AgPasture (Li et al. 2011), and the forage rape crop was simulated with the Canola module (Pembleton et al. 2013). For most model parameters, default values were used. Exceptions were some changes to the N cycling rate to account for the relatively high C content in the soil according to results from Monaghan and Barraclough (1992): the potential nitrification rate was increased to 90 mg N/kg soil/day and the $NH_4$ concentration at half of nitrification rate which was decreased to 30 mg N/kg soil/day. Changes in the Canola module included an increase in leaf size to account for the larger leaves of forage rape cultivars compared with oilseed rape cultivars and an increase of 30% in radiation use efficiency (E. Chakwizira, *pers. comm.*). Also, water use was restricted below the depth of 20 cm and the uptake of both $NO_3$ and $NH_4$ was enabled (Malagoli et al. 2004). In AgPasture, the rooting depth changed as a simple linear function of root mass to mimic germination and seedling development, with maximum rooting depth set to 100 cm; the specific leaf area was set to 24 $m^2$/kg and the specific root length was set to 120 m/g. Based on experimental results (Drewry et al. 2001) the minimum macro-porosity for optimum plant growth was set to 15%, and the coefficient for growth limitations due to soil moisture saturation was increased to from 0.1 to 0.25.

Simulations were run with daily weather data from Lincoln Broadfields' weather station (43.629$^o$S, 172.471$^o$E) and the Flaxton Deep Silt Loam soil (Table **1**). Firstly a base simulation was set up according to the experimental design, which included the treatments +/- urine application and +/- treading. The detailed management of the experiment was described using the APSIM manager scripts (Moore et al. 2014). APSIM had to be modified to allow dynamic changes of parameters within the soil module, such as macroporosity, bulk density and hydraulic conductivity; the changes are controlled using manager scripts. The effect of treading on soil physical properties (Table **1**) was defined based on patterns from Drewry et al. (2001) and the bulk density values determined in the experiments described above.

To investigate the effect of fallow period between winter forage grazing and ryegrass sowing on N leaching a second set of simulations was set up, again including +/- urine application and +/- treading. Leaching losses were defined for the depth of 1.0 m and all the simulations were run for the same year (2012). Rape was sown on the 1$^{st}$ of March and N fertiliser (50 kg N/ha) was applied on the 20$^{th}$ of March and the 30$^{th}$ of April. Forage rape was cut at 20 cm above ground level on 1$^{st}$ of August, followed by urine application at a rate of

600 kg N/ha, and ryegrass was either sown on the 15th of September (fallow period of 45 days) or the 15th of October (fallow period of 75 days). The ryegrass was cut to a residual of 1400 kg DM/ha whenever the dry matter exceeded 2500 kg DM/ha. After cutting, N fertiliser was applied at a rate of 20 kg N/ha. Irrigation was applied at a rate of 10 mm/day whenever the soil water deficit (SWD) in the upper 60 cm soil profile was $\geq$ 30 mm, and stopped when the SWD $\leq$ 10 mm. The irrigation period was from 15th September to 30th of April.

**Table 1:** Key properties of the Flaxton soil used in the simulations. Sand and clay contents, organic carbon (OC), volumetric water content at permanent wilting point ($\theta_{PWP}$), field capacity ($\theta_{FC}$), and saturation ($\theta_S$), bulk density ($\rho$), and saturated hydraulic conductivity ($K_{SAT}$, mm/day). Values in brackets were used for the treaded soil.

| Soil depth (cm) | Sand (%) | Clay (%) | OC (%) | $\theta_{PWP}$ (%) | $\theta_{FC}$ (%) | $\theta_S$ (%) | $\rho$ ($Mg/m^3$) | $K_{SAT}$ (cm/h) |
|---|---|---|---|---|---|---|---|---|
| 0-10 | 5.0 | 31.5 | 4.5 | 19 | 39 | 52 (46) | 1.25 (1.34) | 12.3 (2.2) |
| 10-20 | 5.0 | 31.5 | 4.0 | 20 | 36 | 45 (44) | 1.33 (1.39) | 4.3 (1.7) |
| 20-35 | 2.5 | 33.5 | 1.5 | 19 | 30 | 36 | 1.61 | 0.53 |
| 35-60 | 5.0 | 35.0 | 0.4 | 16 | 29 | 36 | 1.70 | 0.08 |
| 60-85 | 40.0 | 16.0 | 0.3 | 17 | 32 | 37 | 1.66 | 0.06 |
| 85-110 | 50.0 | 12.0 | 0.2 | 18 | 32 | 37 | 1.65 | 0.04 |
| 110-150 | 50.0 | 12.0 | 0.2 | 20 | 34 | 38 | 1.64 | 0.04 |

## Results and Discussion

### *Modelling of experimental results*

Average soil moisture was well simulated by APSIM (e.g. of 0-15 cm depth on Figure **1**a). While treading only had a minor effect on simulated soil moisture contents (with a maximum difference of 0.045 $m^3/m^3$ in the top layer (0-15 cm), data not shown). Due to the reduction in porosity, and thus saturated soil moisture content (Table **1**), the degree of water saturation simulated by APSIM was higher following treading on the 18th of July (Figure **1**b).

APSIM simulation of $NH_4$ and $NO_3$ for the different depths was also reasonably well simulated by APSIM (Figure **2**), indicating that the N transformations and transport following urine deposition are captured by the model reasonably well. The concentrations of mineral N in the soil, both measured and simulated, were not significantly affected by treading.

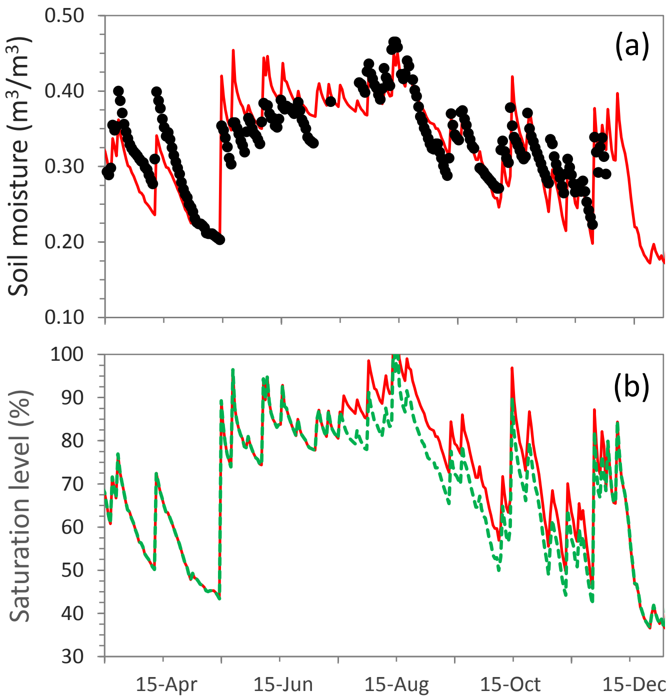


**Figure 1**. Average measured (dots) and APSIM simulated (lines) values of soil moisture, 0-15 cm (a), and the comparison between soil saturation levels simulated by APSIM with (full line) and without treading (dashed line) (b). Treading applied after grazing on the 18th of July

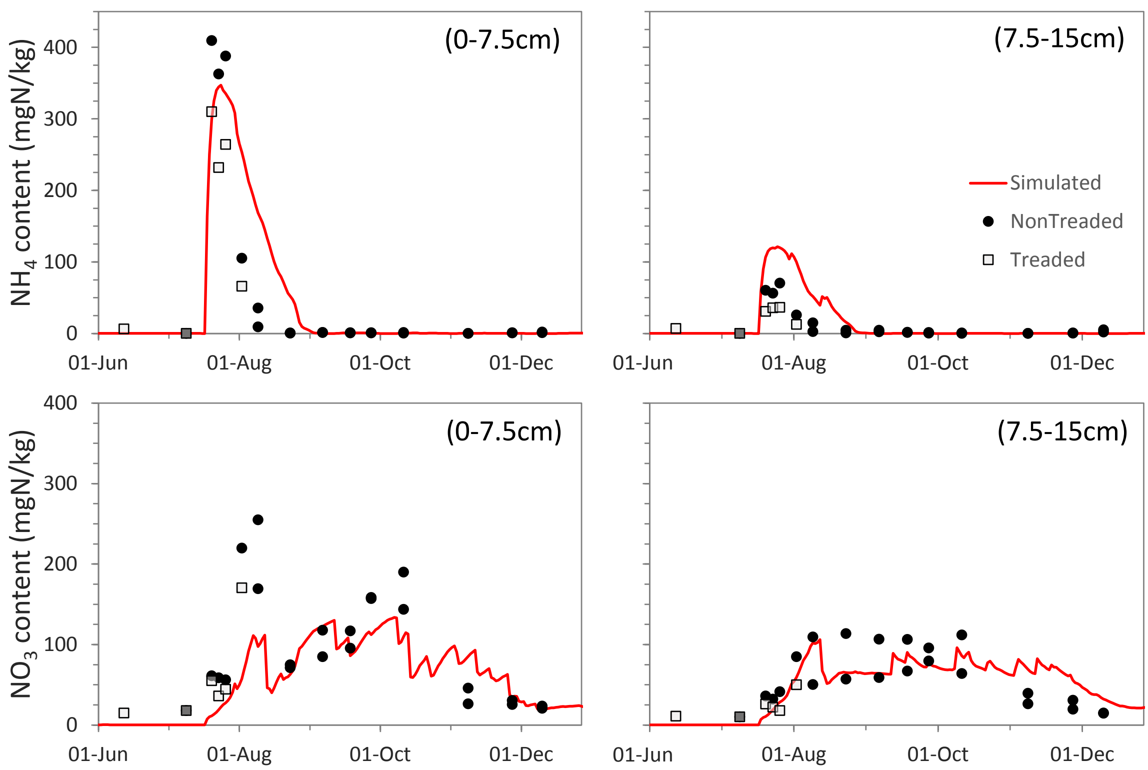


**Figure 2**. Average measured (dots) and simulated (lines) amounts of ammonium ($NH_4$) and nitrate ($NO_3$) in the soil at depth of 0-7.5 cm and 7.5-15 cm. Grazing was simulated on the 18th of July, consisting of treading and urine application at a rate of 600 kg N/ha

The yield of the rape forage simulated by APSIM, 6083 kg DM/ha, was within the range measured, 5077-7065 kg DM/ha (Figure **3**). Simulated ryegrass yield also agreed reasonably well with the measurements under urine, with amounts of 3873 and 4384 kg DM/ha compared with measured values ranging between 3681-4660 and 3698-6738 kg DM/ha for the first and second cut, respectively. The values for the no urine treatment were underestimated by about 50%. For this situation, simulated pasture growth was low due to insufficient soil N supply, likely linked to low rates of organic matter mineralisation. Despite a decrease in macroporosity from 13% to 7% in the top layer following treading, APSIM did not predict an effect of treading on ryegrass growth. This result was also in agreement with measurements and might be due to the fact that the soil moisture level in the top 15 cm was relatively low at the time of re-grassing, on the 25$^{th}$ of September (Figure **1**). Soil saturation level has exceeded 75% in only 20 days in the treaded simulation scenario compared to 12 days in the non-treaded scenarios. Thus, growth limitations due to soil moisture saturation would have been affected only to a small extent. The lack of a treading effect in the measured data also suggests that resistance to root penetration was not a major issue either, and so this was not accounted for in the simulations.

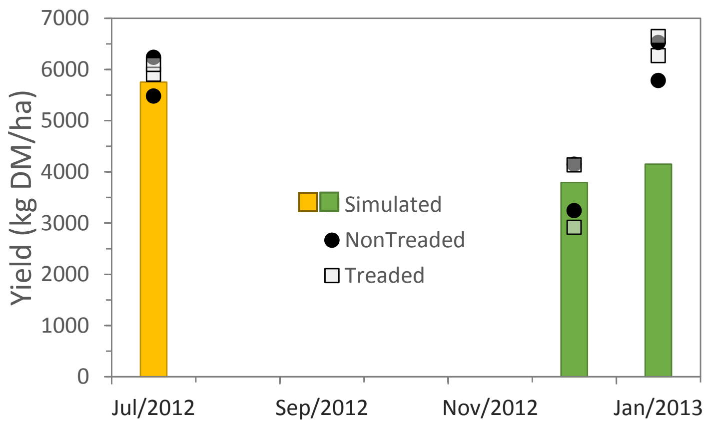


**Figure 3**. Measured (dots) and APSIM simulated (bars) dry matter yield (kg/ha) for forage rape, harvested in July, and ryegrass, harvested in December and January

### *Nitrate leaching from fallow scenarios*

APSIM simulated that nitrate-N leaching following winter grazing of forage rape and urine application at a rate of 600 kg N/ha was 55% higher when the fallow period was increased from 45 to 75 days (Table 2). Again, treading had only a minor effect on simulated N leaching. N leaching from non-urine patches was on average 27 kg/ha/year.

To estimate paddock scale annual N leaching from the winter forage-ryegrass rotation with a stocking density of 600 cows/ha grazing over a period of 4 hrs, we assumed a daily urination frequency of 10 urinations/cow and a urine patch area of 0.3 m$^2$, giving a urine patch coverage over the paddock of 14% (Pleasants et al. 2007). Based on the N leaching results for urine and non-urine affected areas (Table **2**), paddock scale N leaching equated to 32 kg N/ha for the short fallow scenario, and 40 kg N/ha for the longer fallow scenario. These leaching estimates are from the deposition of urine during winter grazing of the forage only and do not take into account any leaching from urine deposited onto the paddocks during prior or subsequent grazings.

**Table 2:** APSIM simulated annual nitrate ($NO_3$) leaching at a depth of 1.0 m for two different scenarios (fallow periods)

| Length of fallow period (days) | Urine deposition | Treading simulated | Ryegrass sowing date | $NO_3$ leaching (kg N/ha) | Paddock scale N leaching (kg N/ha) |
|---|---|---|---|---|---|
| 45 | yes | no | 15/Sep | 76 | 32 |
| | no | no | 15/Sep | 26 | |
| | yes | yes | 15/Sep | 73 | 32 |
| | no | yes | 15/Sep | 26 | |
| 75 | yes | no | 15/Oct | 118 | 40 |
| | no | no | 15/Oct | 29 | |
| | yes | yes | 15/Oct | 115 | 40 |
| | no | yes | 15/Oct | 29 | |

## Concluding remarks

The simulation study demonstrates that APSIM, with its ability to simulate plant growth and soil nitrogen cycling, can be used to investigate the effect of winter forage grazing systems on nitrate leaching. However, more information is needed for developing a comprehensive description of the effects of treading on the soil-plant environment, including the effect of stocking rate and grazing duration on soil physical properties and the effect of treading on plant growth.


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